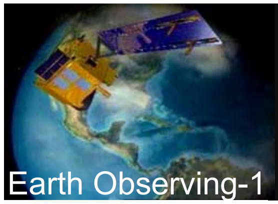





# Section 21

## Lightweight Flexible Solar Array (LFSA)

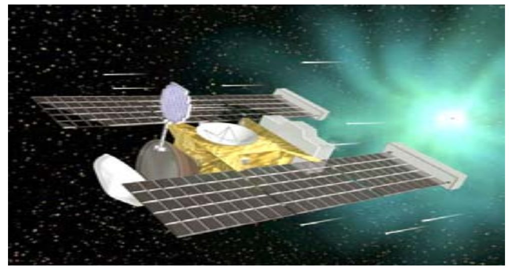
***. . . John Lyons / Bernie Carpenter***

*NASA / Goddard Space Flight Center / Lockheed Martin*

# LFSA EO-1 Flight Equipment

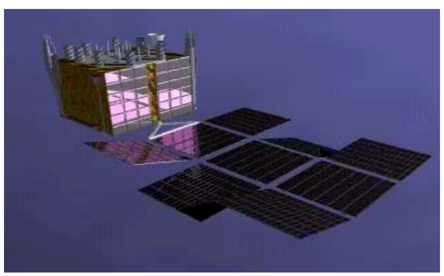
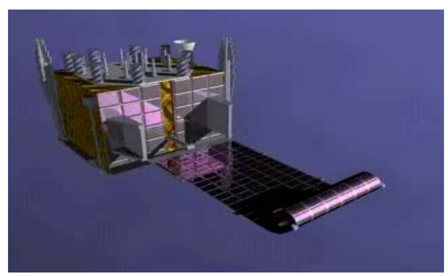
- ***Solar Array Approaches vs. Power Requirement***

***State of Practice:***
***Body Mounted Rigid Array***



**to 1kW**
**< 50 W/kg**

***Lockheed Martin LFSA Concepts:***

| ***Fold-Out Array*** | ***Roll-Out Array*** | ***Inflatable Array*** |
|---|---|---|
|  |  |  |
| **to 1 kW**<br>**> 100 W/kg** | **2 to 8 kW**<br>**> 175 W/kg** | **8 to 20 kW**<br>**> 200 W/kg** |

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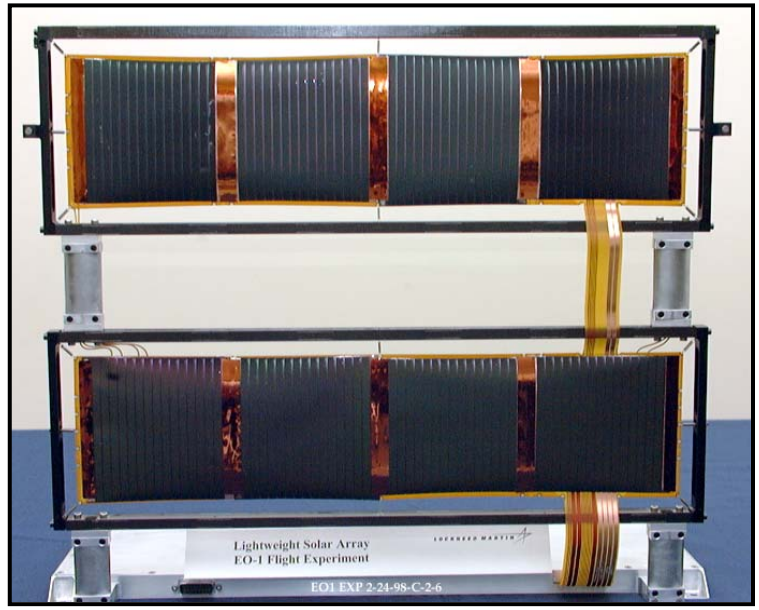
# EO-1 LFSA Experiment



- ***Components***
  - *Thin Film CIS on Polyimide*
  - *SMA Hinges*
  - *Ball-Lock Launch Lock*
  - *I-V Monitor*
  - *MFS Cable and Instruments*
  - *Spring Type Suspension*
- ***Goal:***
  - *Increase science payload mass fraction by increasing array specific to >100W/kg*
- ***Partners:***
  - *AFRL, NASA LaRC, NASA GSFC, Lockheed Martin Astronautics (Denver, CO)*

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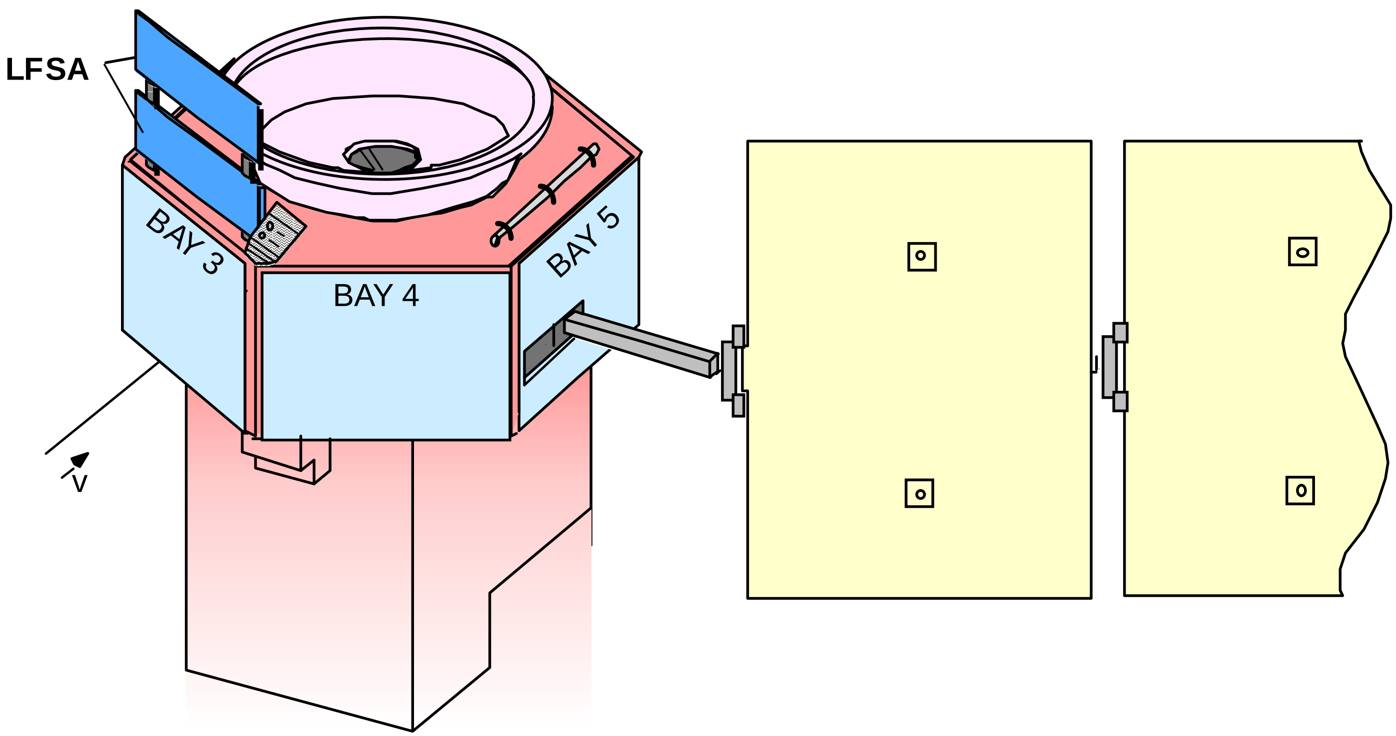
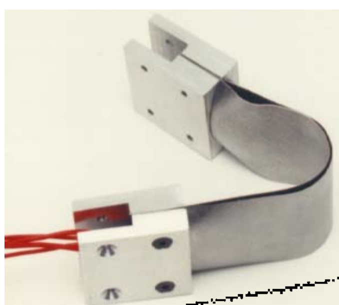
# EO-1 / LFSA Configuration





# SMA Deployment Hinge

STOWED

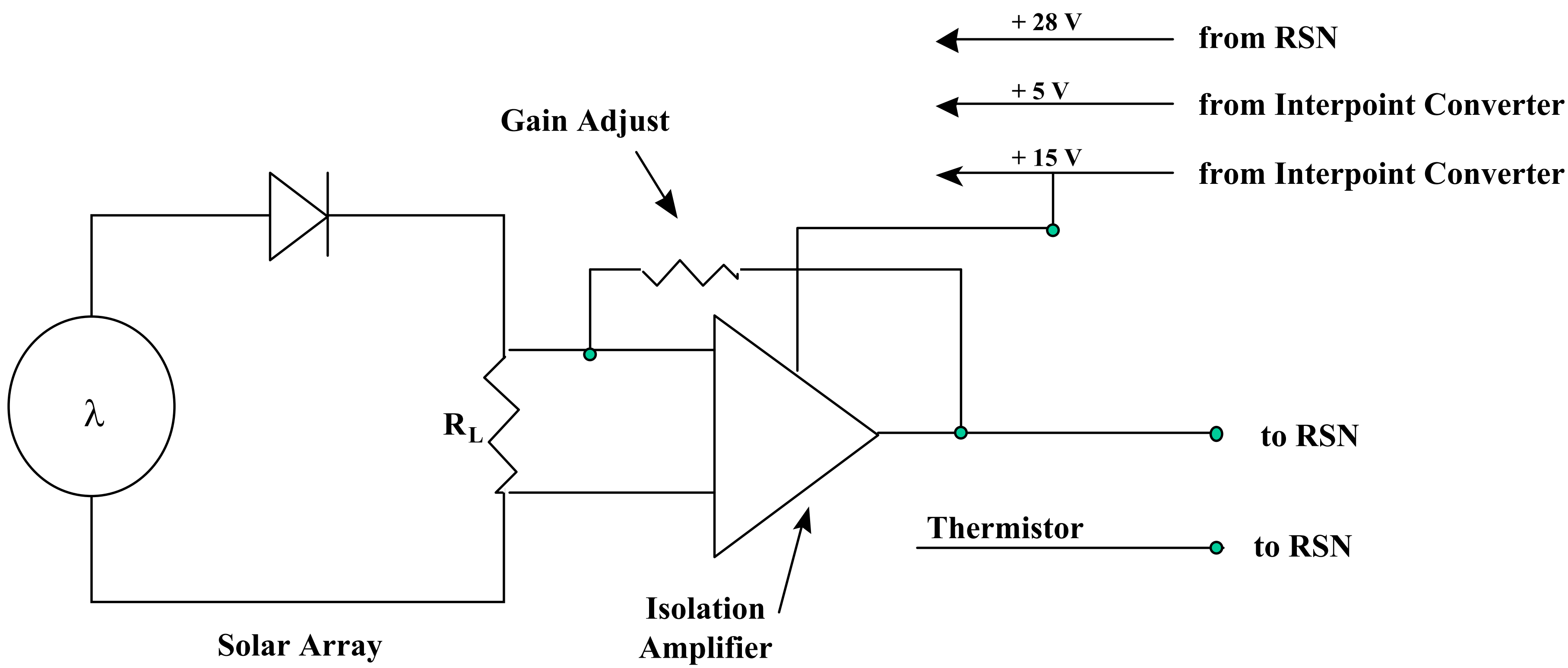


DEPLOYED

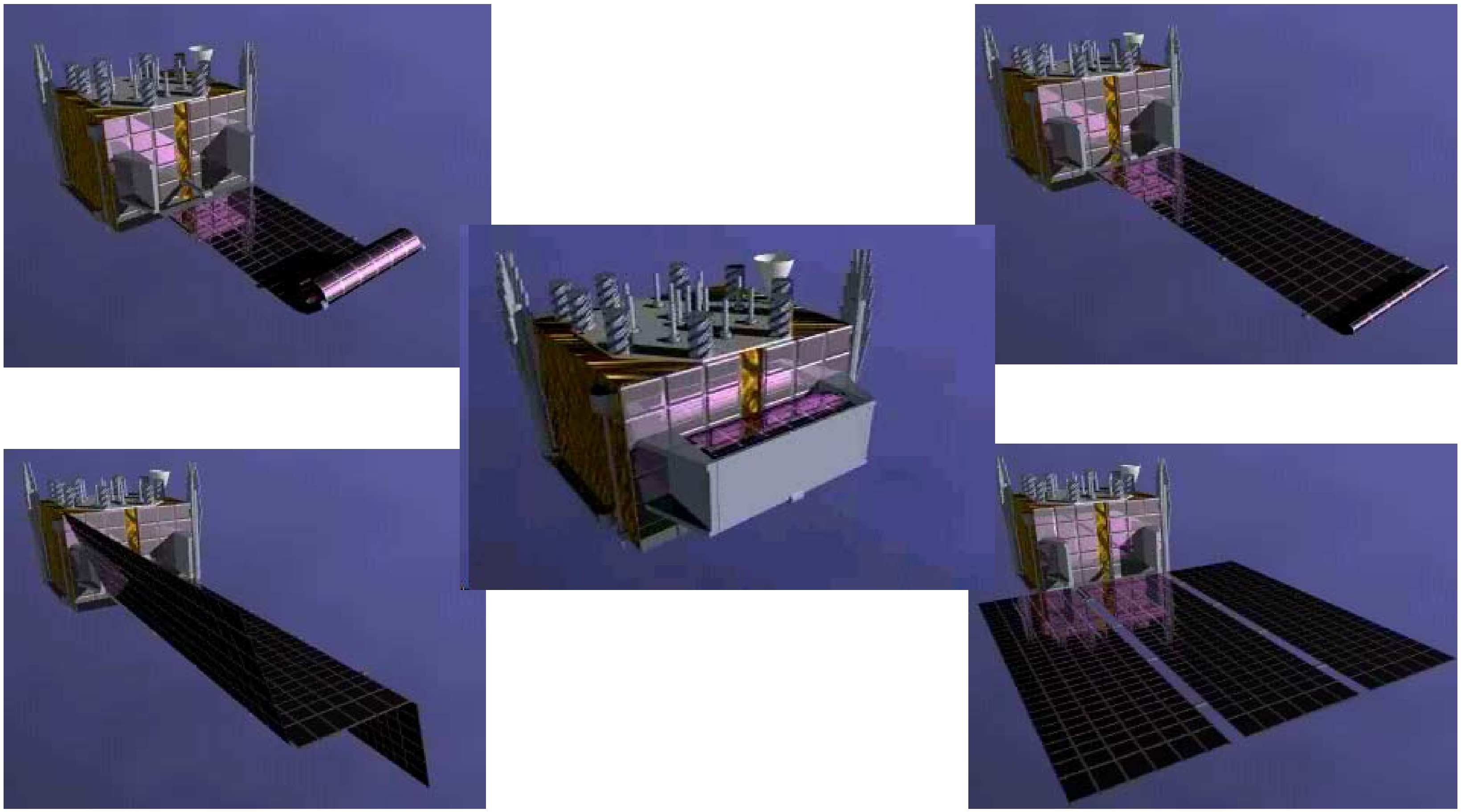
- **Operation Events**
  - *Deployment controlled by heating SMA*
  - *SMA may be designed to either drive or damp deployment*
  - *Minimizes deployment loads to allow lighter weight structure*
  - *Can use passive solar heating to assist or power deployment*
- **Device Attributes**
  - *Absence of moving parts increases reliability*
  - *Minimal part count*
  - *No freeplay in deployed configuration*

# CIS I-V Curve Sweep Block Diagram





# LFSA Rollout Array Concept



# LFSA Verification

- ***Tests at Lockheed Martin***
  - ***Thermal (non-vacuum)***
  - ***Random Vibration (15 gRMS, 3 min/axis)***
  - ***Thermal Vacuum (8 cycles, -40 to +80°C)***
  - ***Functional Tests***
    - *Deployment*
    - *PV Output*
    - *Electrical Performance*

| Thermal (non-vacuum) | → | Random Vibration | → | Functional Test | → | Thermal-Vac Cycling | → | Functional Test |
|---|---|---|---|---|---|---|---|---|
| -Check deployment and PV output at temp. extremes | | -Check hardware robustness under launch loads | | -Check for loss of function/ performance | | -Check hardware robustness under thermal loading | | -Check for loss of function/ performance |

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# Functional Testing



- ***LFSA***
  - ***Launch Restraint Release and Deployment***
    - *Verifies working of shape memory release mechanism and panel hinges*
  - ***CIS Solar Panel I-V Curve Sweep***
    - *Verifies working of photovoltaic array*

# LFSA Experiment Validation Objectives

- ***Demonstrate Controlled Deployment:***
  - *Use Shape Memory Actuation to release launch retention mechanism followed by activation of shape memory hinges*
  - *Material is heat-treated in deployed position during fabrication, then low-temperature material (martensite phase) is deformed into stowed shape. When material is heated (as during deployment), the original heat-treated shape is recovered. After heater is turned off, heat-treated shape is maintained.*
- ***Evaluate Photovoltaic Performance:***
  - *Monitor LFSA current, voltage, temperature trends to determine on-orbit degradation in vacuum, thermal cycle, radiation, atomic oxygen environments*

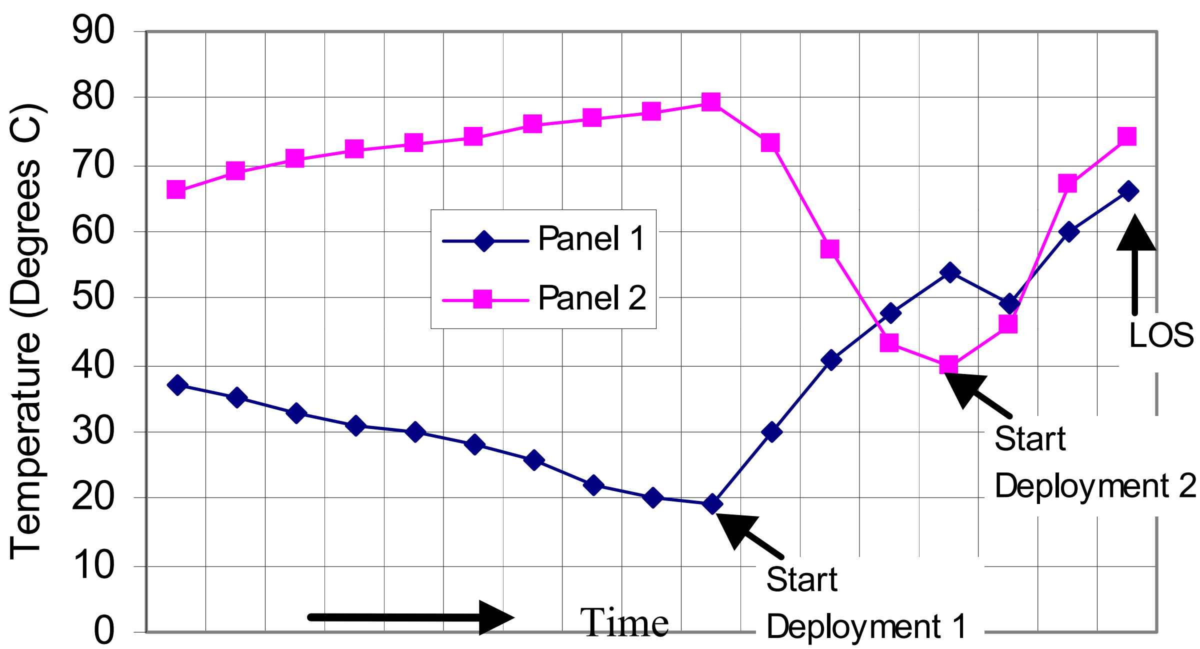
# LFSA Operations

- ***L&EO Operations***
  - ***Performed at Launch plus 7 days***
  - ***Deploy LFSA array via commanding the release of a stow pin, which in turn allowed shaped memory hinges and deployment systems to deploy the LFSA***
  - ***Deployment took ~30 seconds and was done during eclipse exit during a pass while instrument operations were not occurring***
- ***Weekly On-Orbit Operations***
  - ***Perform LFSA I-V Curve Sweep data collect***
    - *Use stored commands to: enable storage of LFSA data, start I-V Curve Sweep mode, change mode back to normal, and disable LFSA data storage*
    - *I-V Curve Sweep takes 10 seconds*
    - *Performed in sunlight, with the preference that the spacecraft be in a position where the sun is at an optimal angle on the array (i.e., near 90°)*
    - *Provide data (FDSS STK data) from which LFSA validation team can derive sun angle during data collect*
    - *Provide LFSA validation team a time history of LFSA raw and calibrated telemetry gathered during I-V curve collects in tabular and plot forms via Excel*
- ***Special On-Orbit Operations***
  - ***Perform additional I-V Curve Sweep data collects (up to 3 / orbit) – as requested***

# LFSA On-Orbit Performance *(1 of 3)*



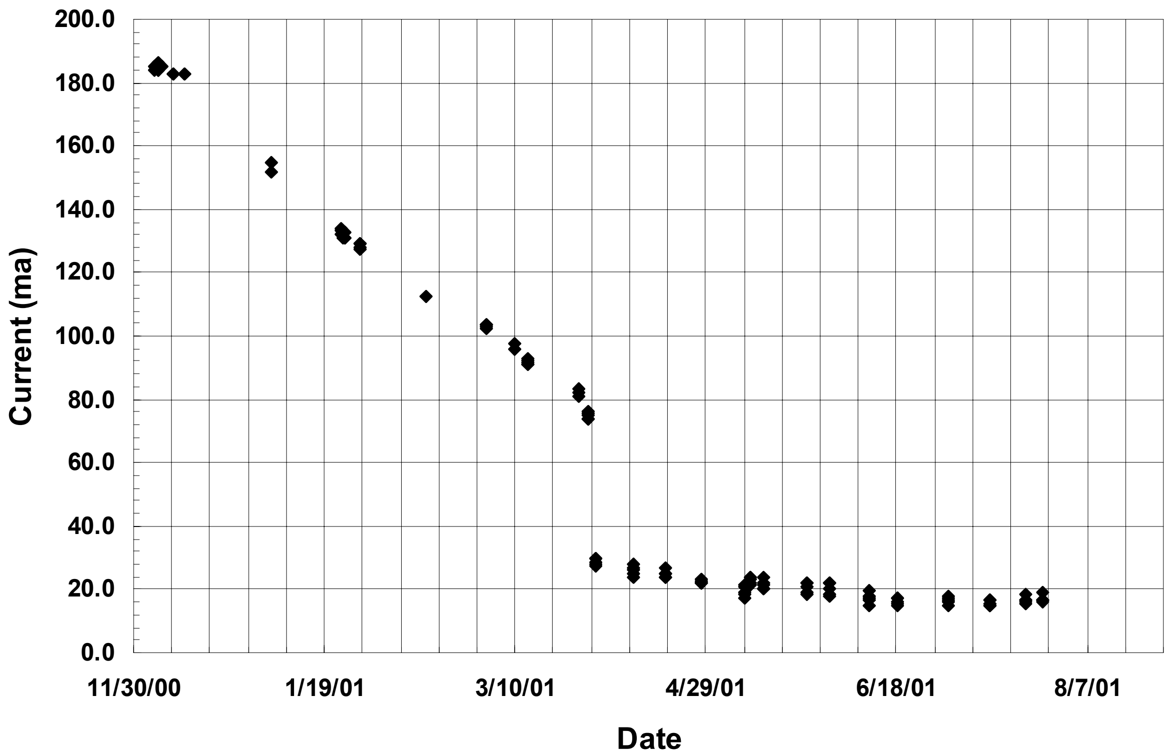
- ***SMA release and deployment was nominal based on switch release indicator and panel temperature profiles.***



# *LFSA On-Orbit Performance (2 of 3)*



- ***Initial current output consistent with ground module measurements***
- ***Anomalous degradation in current output was observed***
- ***Step decrease in output in late March 2001***



# *LFSA On-Orbit Performance* *(3 of 3)*



- ***Rapid thermal cycling was initiated at Lockheed Martin to attempt to duplicate on-orbit performance***
- ***Tests in progress. Early results indicate degradation in solder joints between CIS and flex harness used to carry current from the cells to LFSA measurement electronics.***

# *LFSA On-Orbit Performance Conclusions*

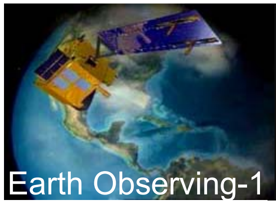


- ***Work needed in developing a good solder joint between CIS and harness.***
- ***Further development is needed on CIS solar cells to increase efficiency of large-area modules (small cells at approximately 7% AM0 efficiency).***
- ***In meantime, amorphous silicon (approximately 9% AM0 efficiency) is the most mature thin-film solar cell technology. Can be used with LFSA concept.***

# LFSA Technology Transfer & Infusion Opportunities



- ***Aeroastro, Inc. missions will use LFSA technology as primary power system, possibly with amorphous silicon thin-film solar cells***
- ***Sport will use thin-film cells attached to its aerobrake (similar to rollout array design)***
- ***Encounter requires six fold-out panels totaling 35 W***




# Lessons Learned



- ***Thin Film PV continues to be an evolving technology. Process sensitivity and scalability tend to limit device efficiency. Efficiency is improved through the use of high temperature processes but these have forced the use of metallic substrates vs. polyimide as used on EO-1.***
- ***Flight opportunities are necessary to move the technology forward. They provide the means of total system verification as well as on-orbit performance.***
- ***Interconnect technology needs to be advanced. It is not sufficient to have high performance PV material and rely on traditional methods of creating electrical connections.***

# Summary / Conclusions

- ***The EO-1 LFSA experiment demonstrated critical technologies associated with future light weight solar array development***
- ***Flight qualification data and methodology provides the basis for future array builds***
- ***Leveraging LSA and DUST programs to fabricate primary power sources for Sport and Encounter spacecraft***